The Quantum Cascade Laser as a Terahertz Local Oscillator

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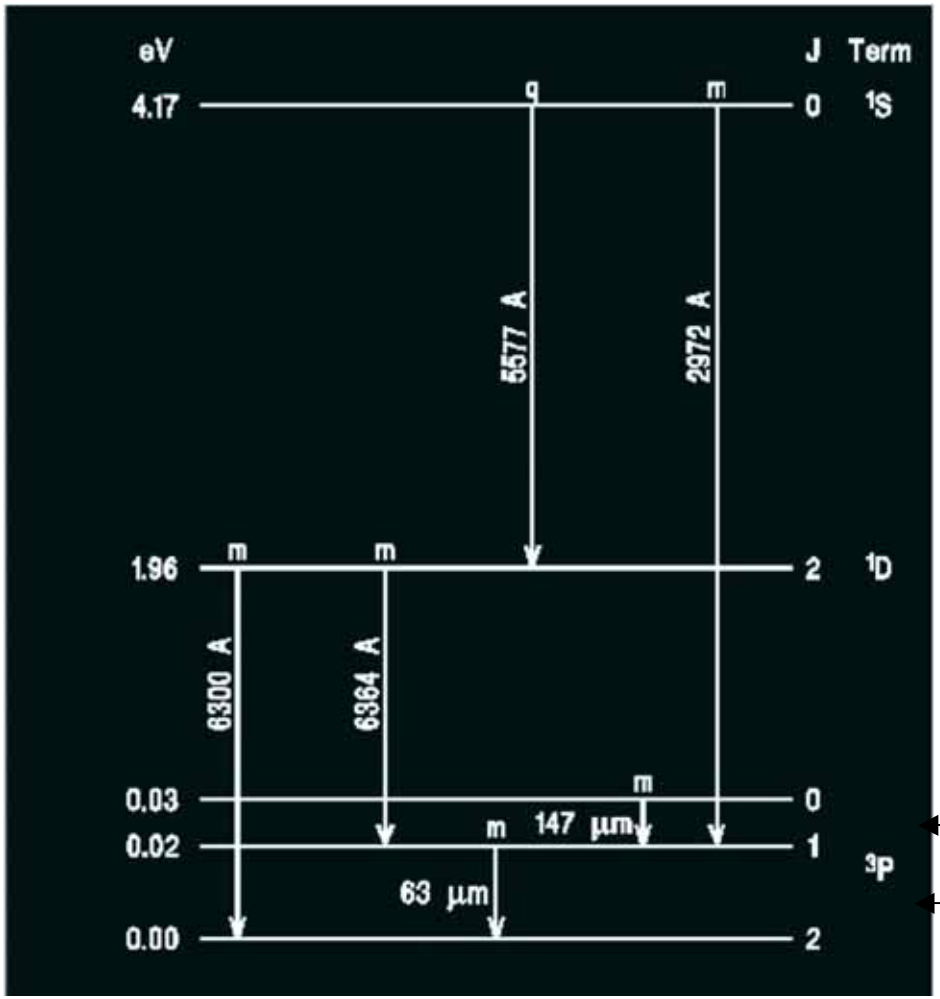
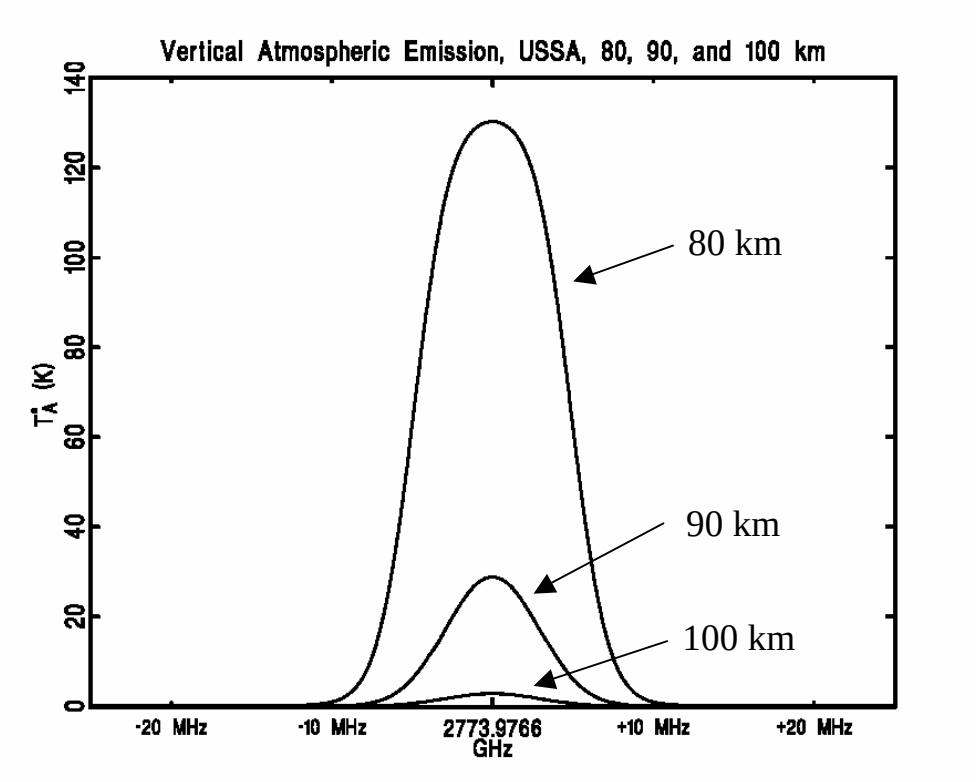
Neutral Atomic Oxygen

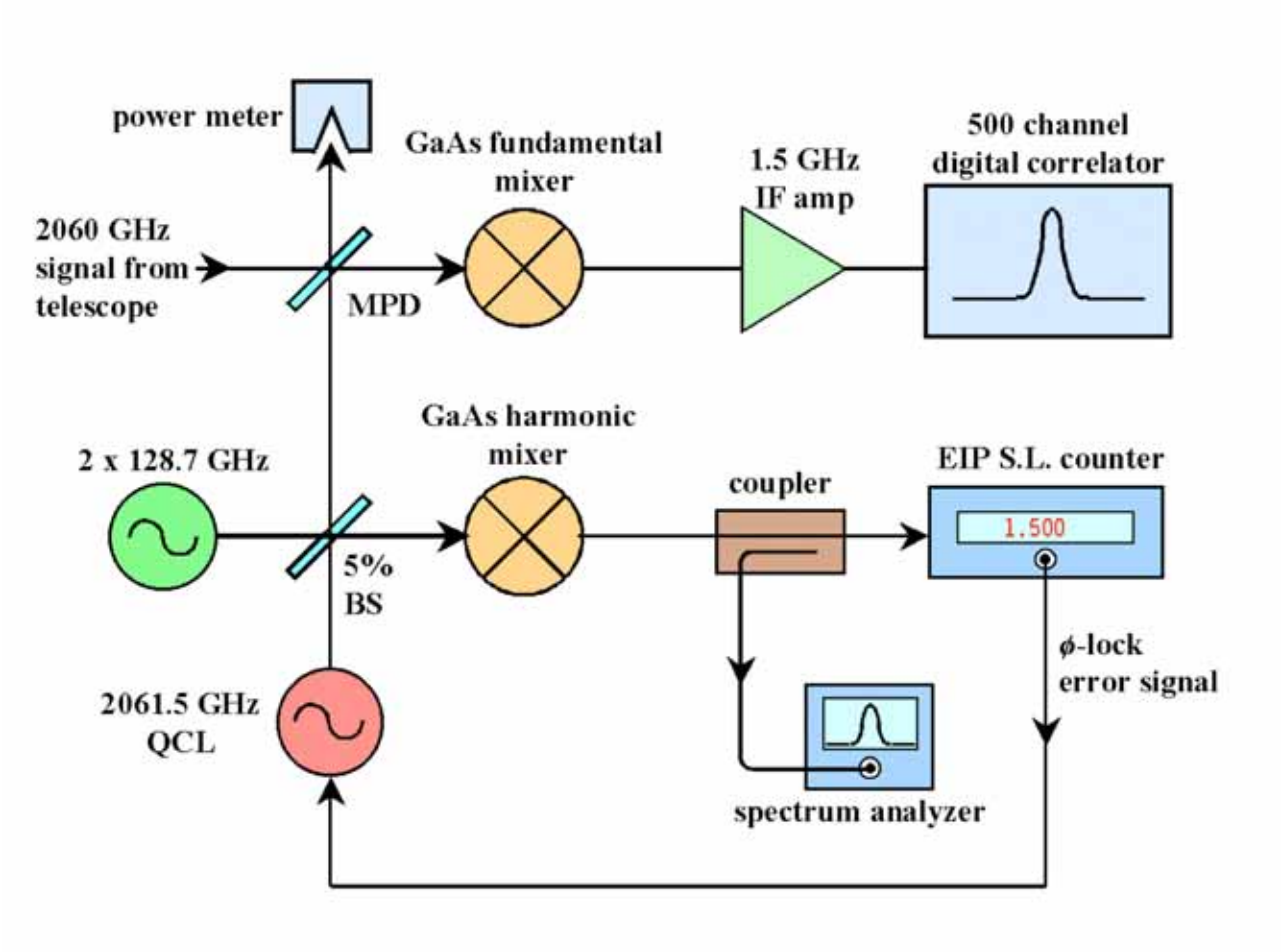


Water Vapor in the Upper Atmosphere



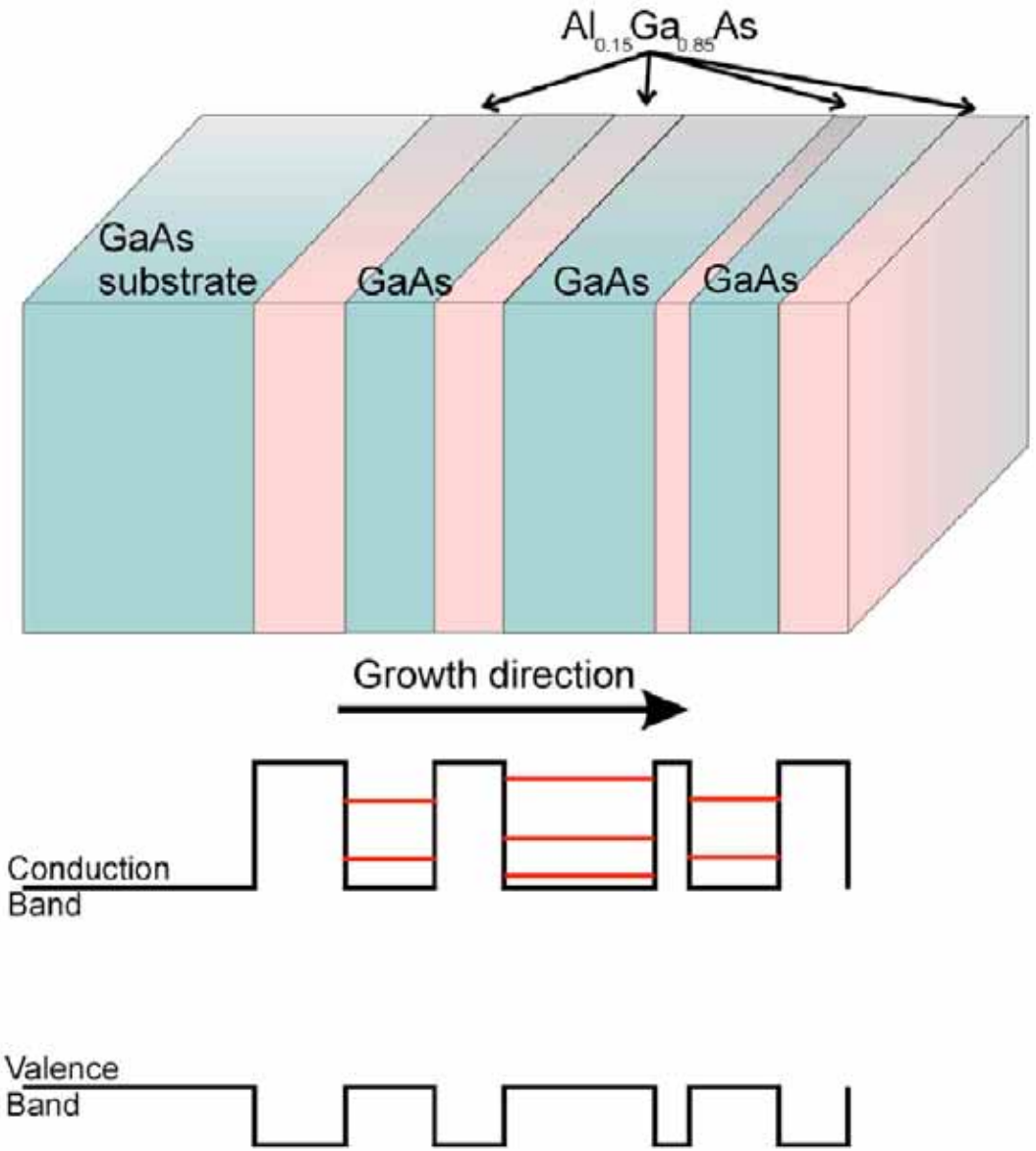
Calculated line profiles of water vapor emission from the 2_{21}-1_{10} transition at 2774 GHz. The receiver is looking up from base altitudes of 80, 90, and 100 km. Linewidths for the two weaker lines are about 8 MHz (FWHM).

Schematic of All-Solid-State THz Receiver



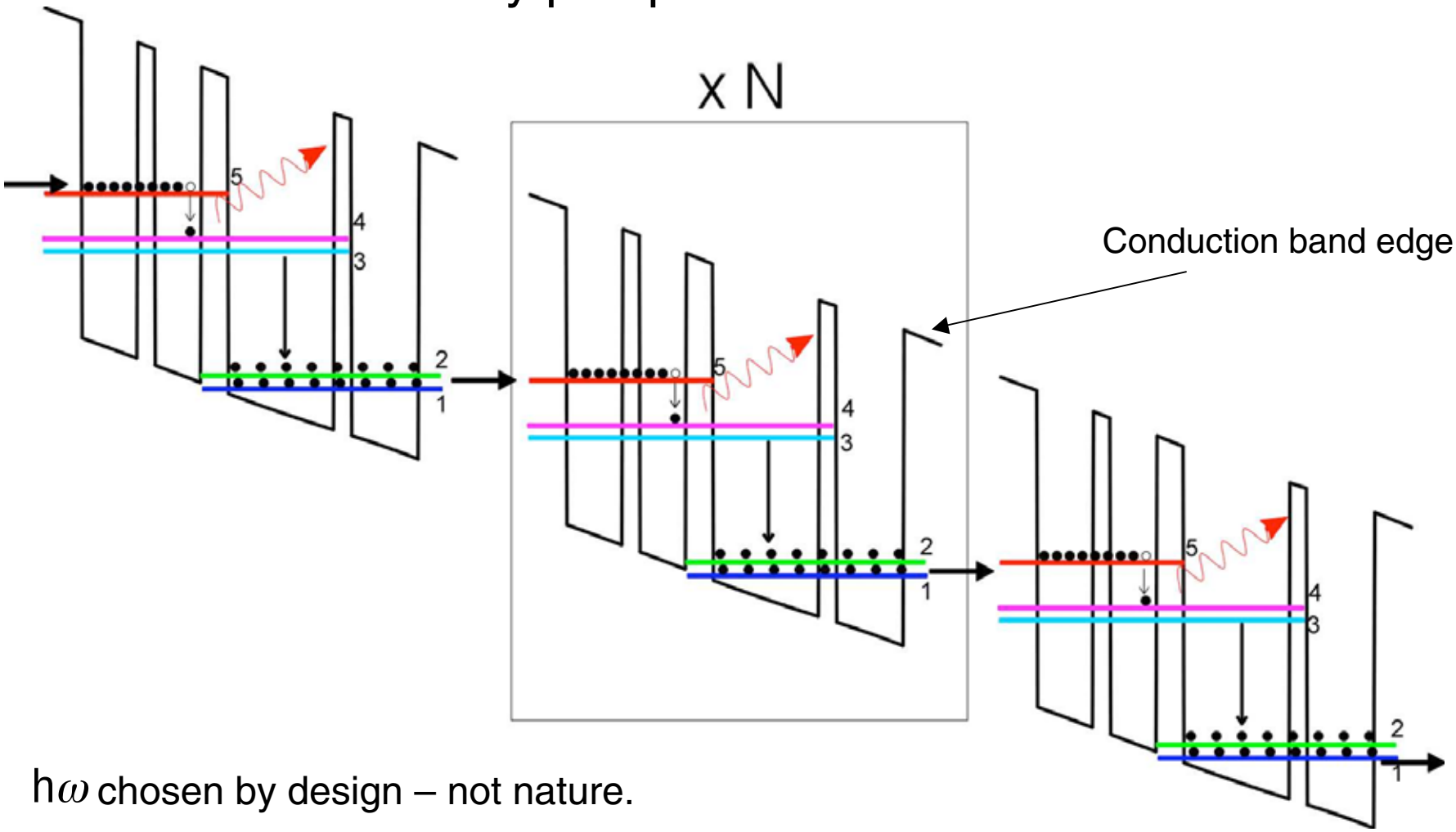
Quantum wells are human-made quantum mechanical systems with energy levels chosen by designers

- GaAs and $Al_xGa_{1-x}As$ are lattice-matched, can be grown on top of each other defect-free.
- Different gap energies in GaAs and $Al_xGa_{1-x}As$ form quantum wells.
- Molecular Beam Epitaxy (MBE) can grow layer by layer, atomically smooth.
- In essence, with MBE we can design and grow "Artificial Atoms" or " artificial molecules." We can control the size of wells and relative energy levels.



Schematic of Quantum cascade laser

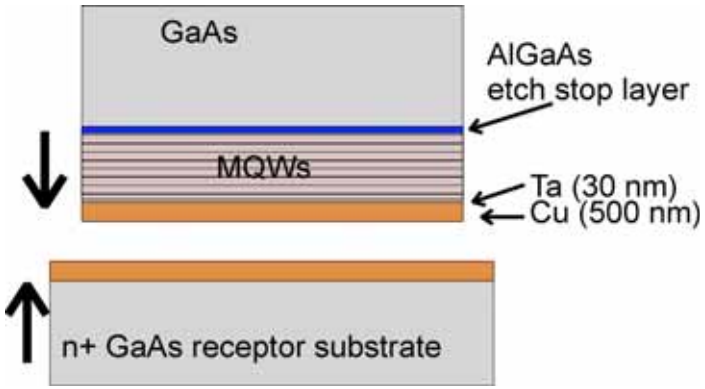
Electrically pumped intersubband laser



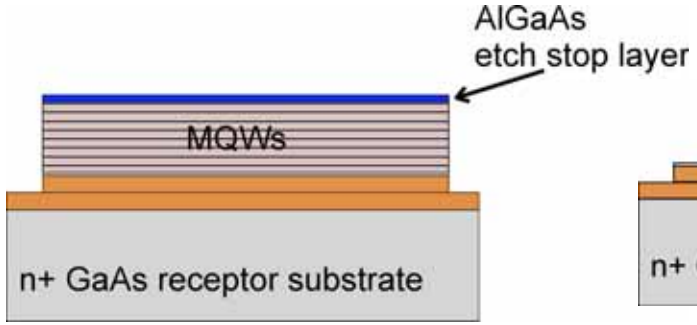
- $h\omega$ chosen by design – not nature.
- Unipolar: electrons make intraband transitions.
- No electron-hole recombination. One electron *cascades* down *N* identical modules, generating *N* photons.

Cu-Cu thermocompression wafer bonding

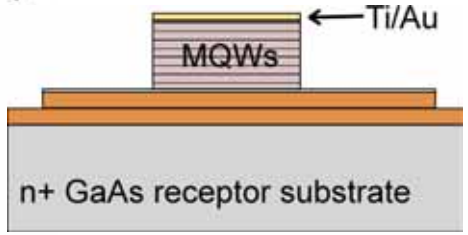
400° C – 60 min
pressure ~ 5 MPa



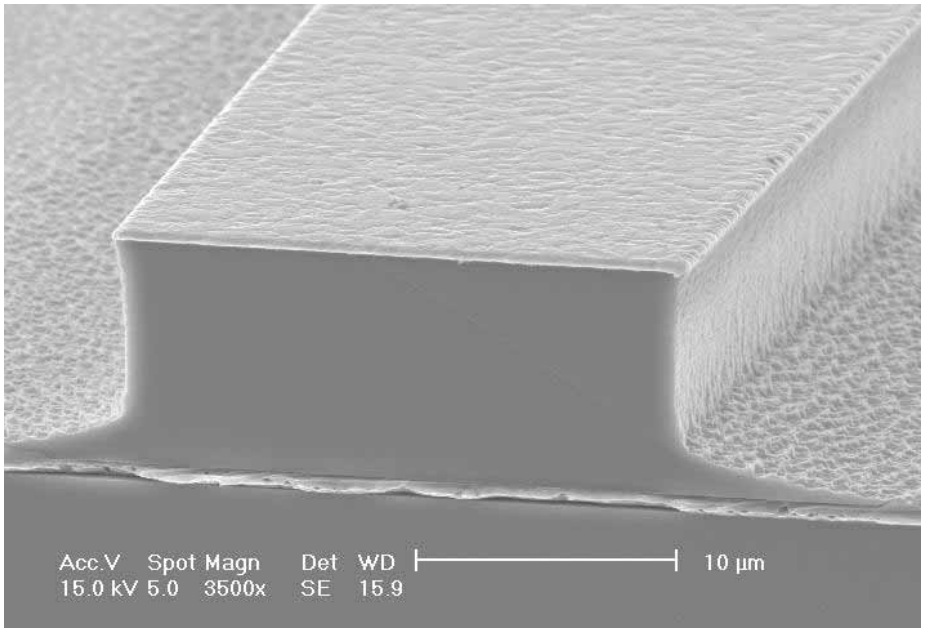
substrate removal



lithography



- Copper — good thermal/electrical conductivity.
- Improved bond quality and stability.
- Fabrication more difficult and requires very clean interface.



QCL Power Curves

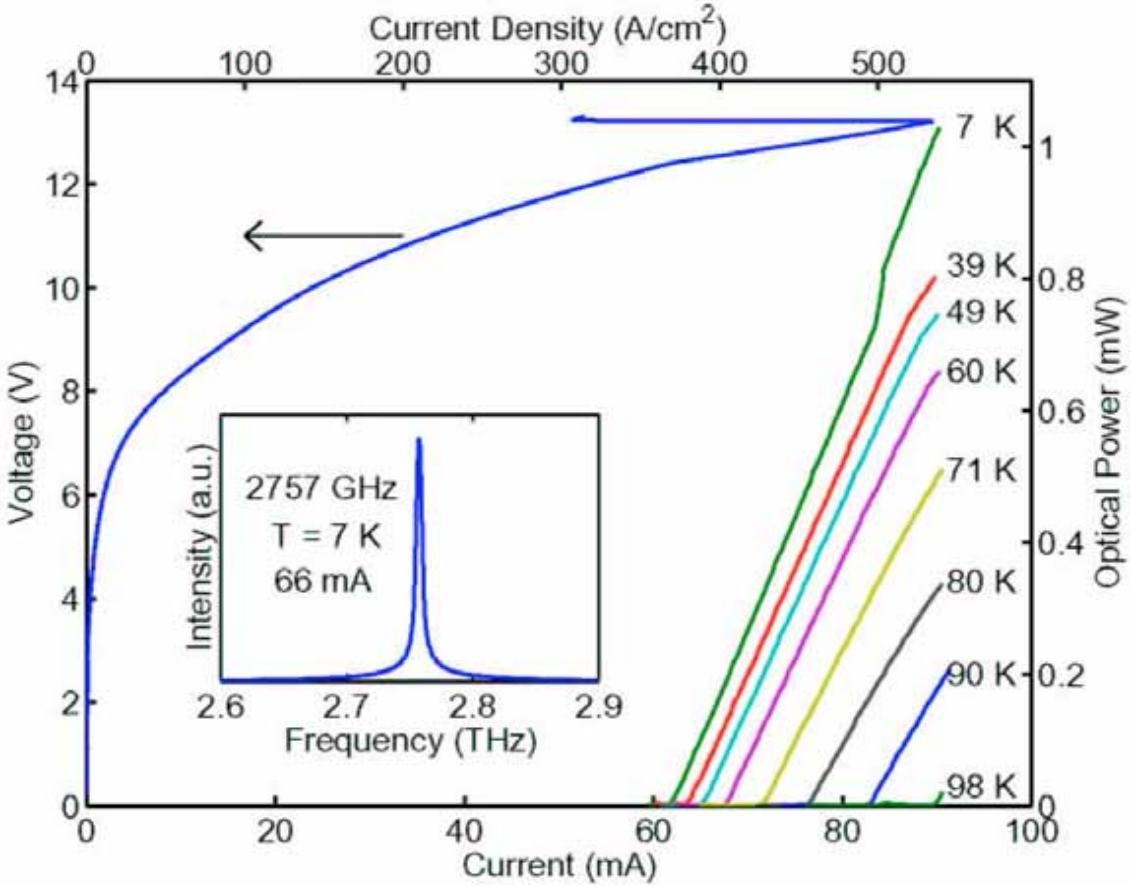
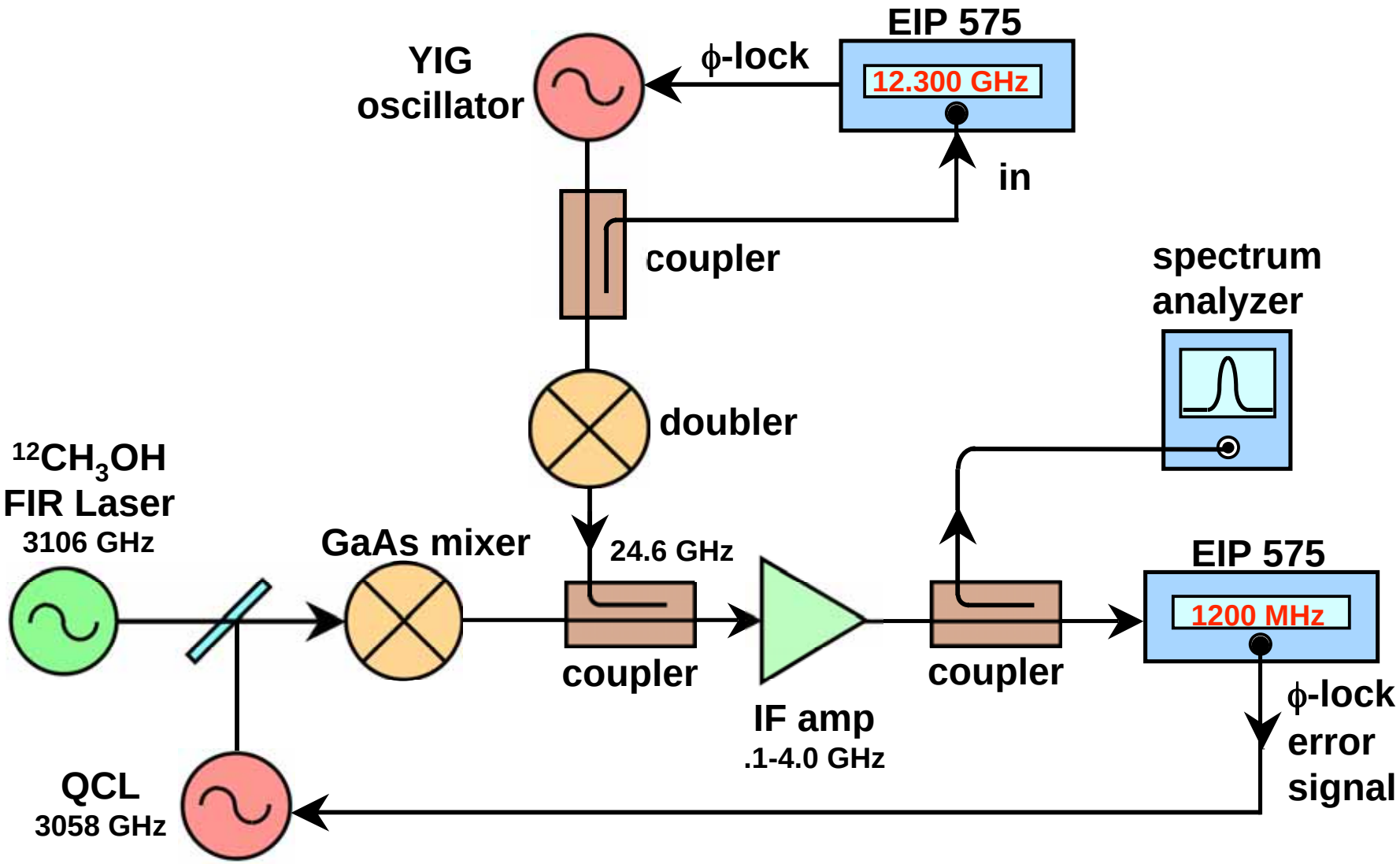
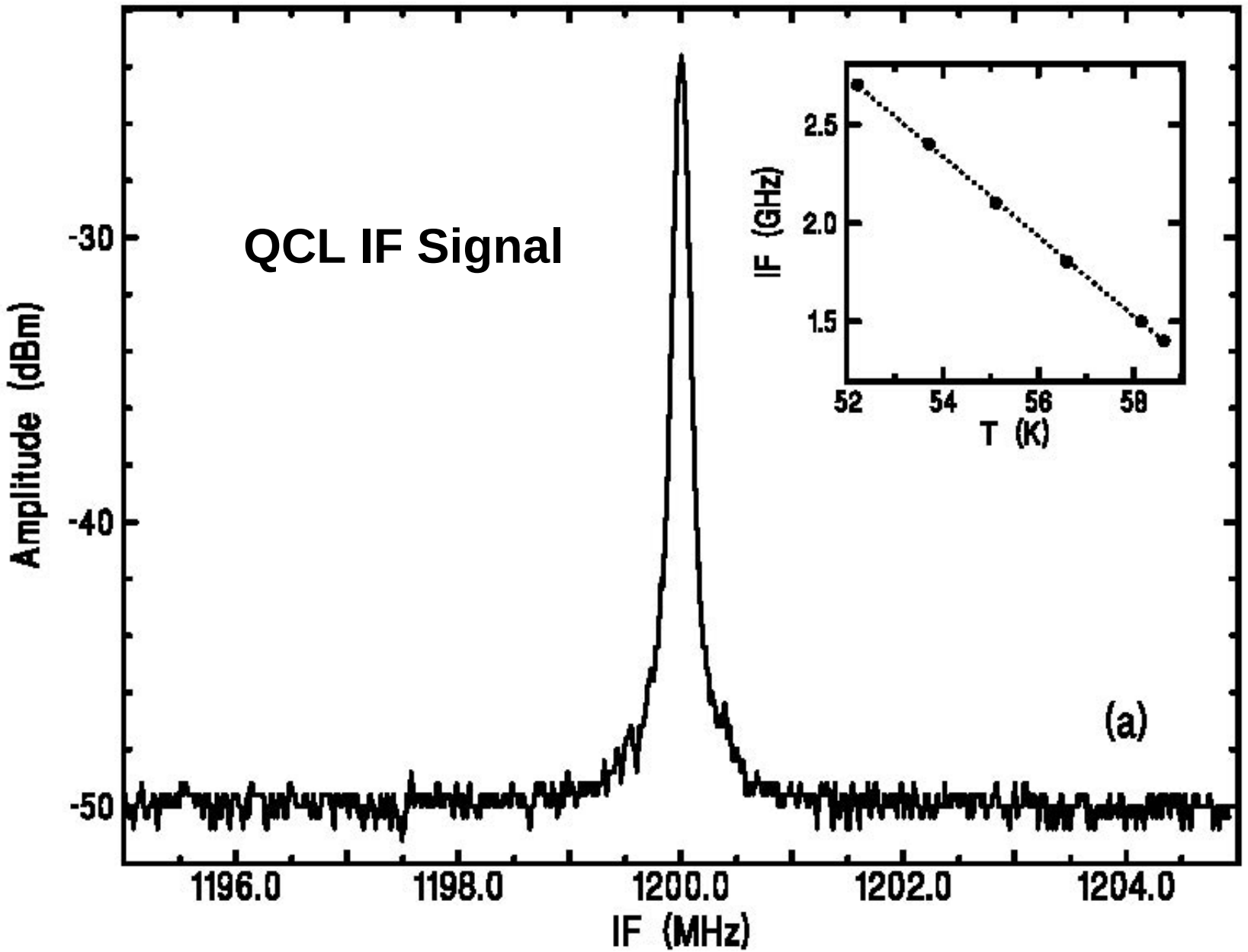
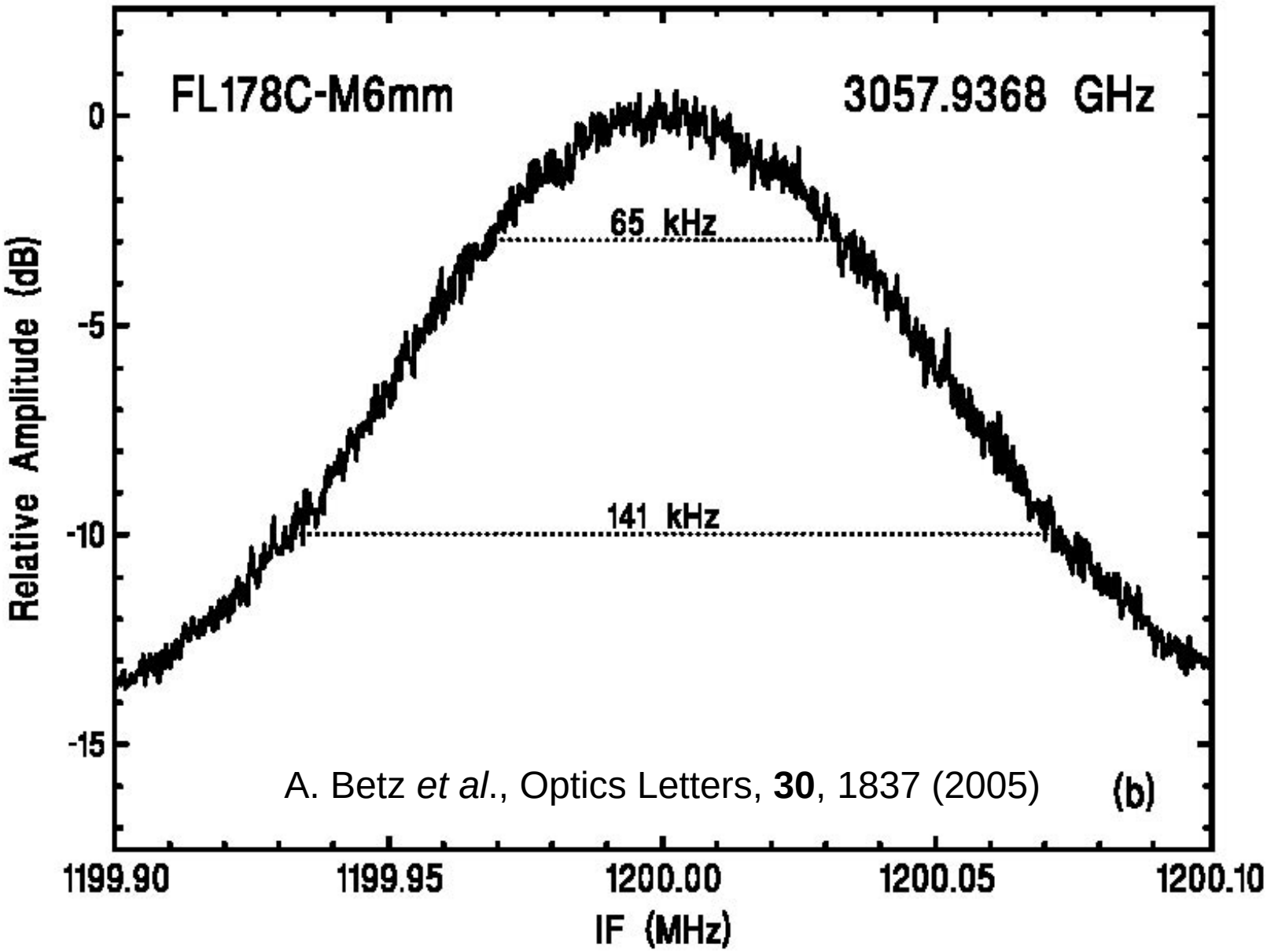


Figure -- Right: QCL emission in CW mode versus current characteristics at various temperatures. (b) Inset: CW spectrum taken using Nicolet 850 Fourier transform spectrometer at 0.125 cm-1 resolution. (c) Left: I/V curve for QCL showing the onset of negative differential resistance above 13.2 V at T=7K



Frequency/Phaselock of THz QCL to FIR Gas Laser

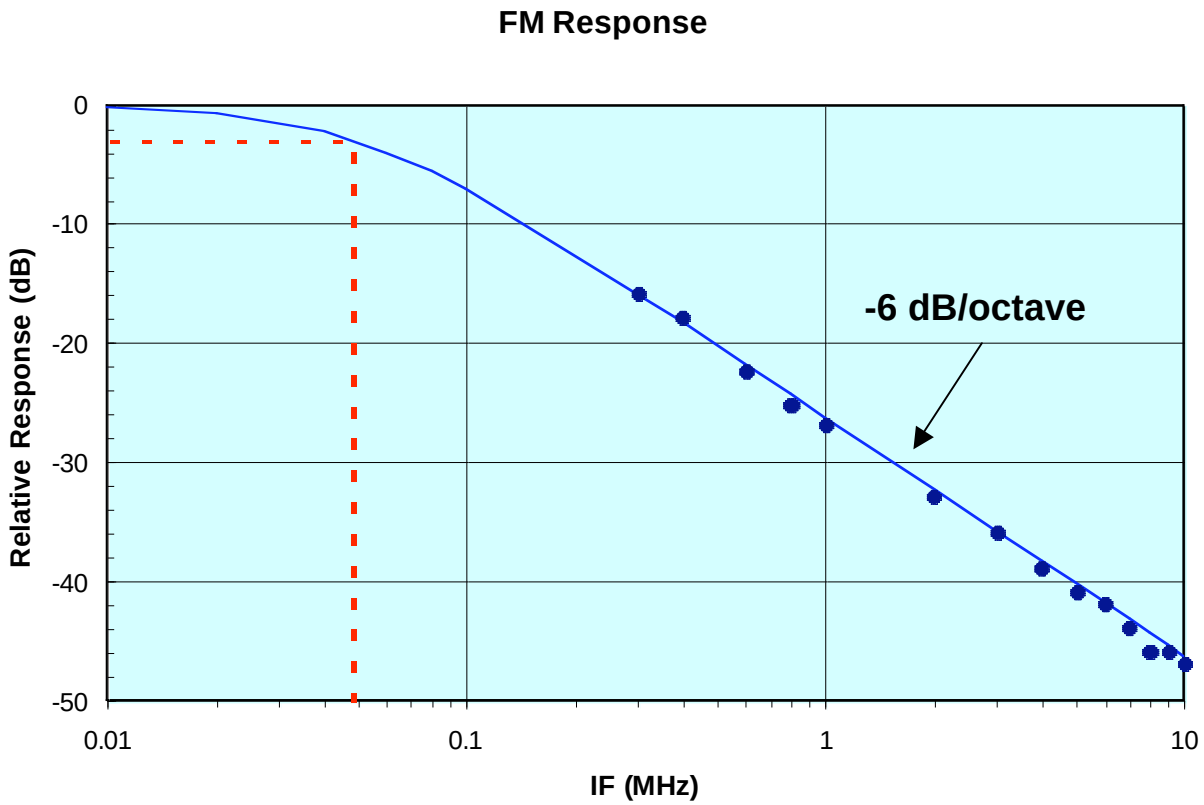

QCL IF Signal
Amplitude (dBm)
-30
-40
-50
1196.0
1198.0
1200.0
1202.0
1204.0
IF (MHz)
(a)
IF (GHz)
2.5
2.0
1.5
52
54
56
58
T (K)



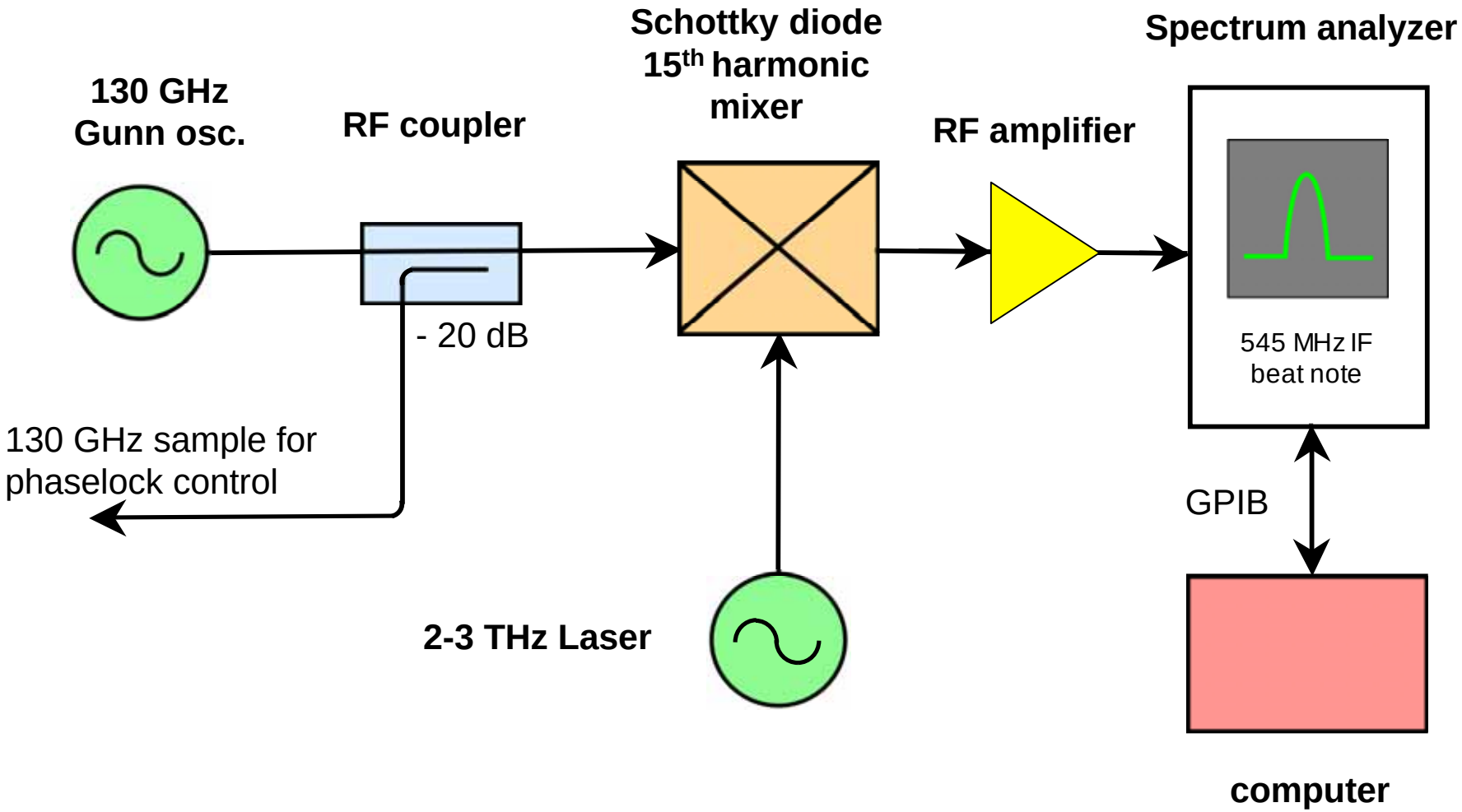
A. Betz *et al*., Optics Letters, **30**, 1837 (2005)

FM Bandwidth

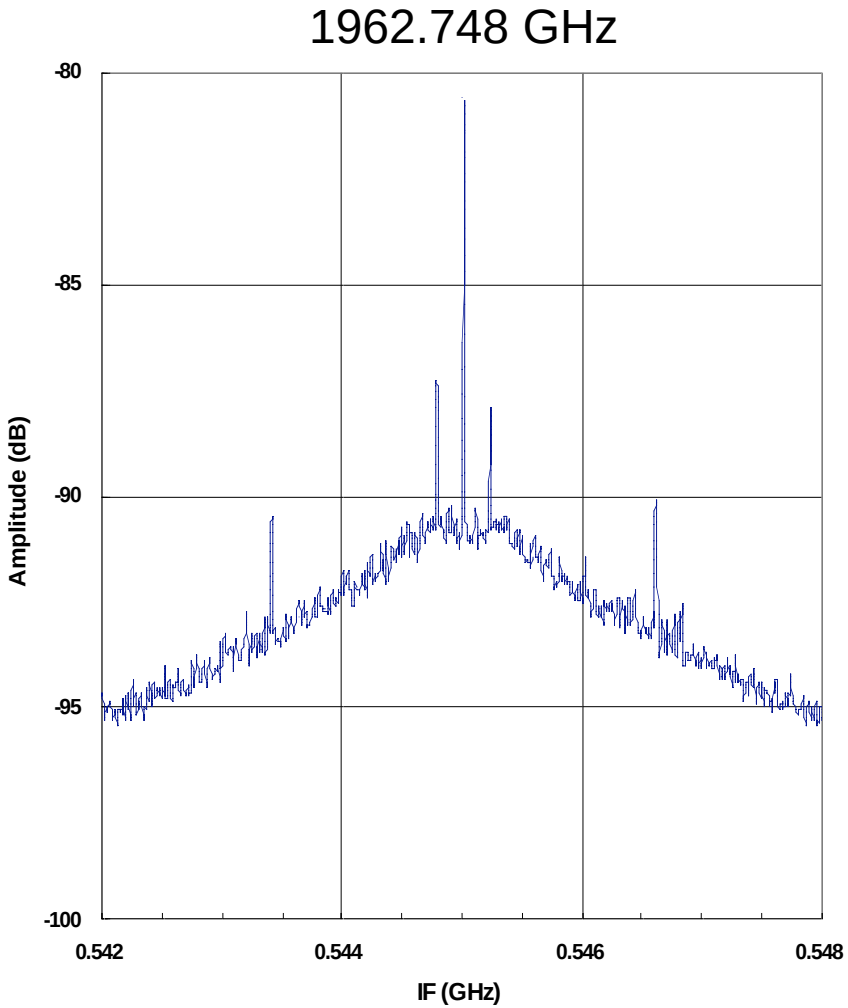
- Frequency of QCL varies inversely with injection current
- Linewidth of FM sideband same as carrier's (e.g., 130 kHz -3 dB)
- FM bandwidth limited by thermal time constant (e.g., f_{-3db} = 48 kHz)



THz Harmonic Multiplier



IF Beat Signal Between FIR Laser and Harmonic of Microwave Source



$f_{laser} = N \times f_{rf} \pm f_{IF}$ (here it's -)

$f_{RF} = M \times 4 \times f_{synth} + 115$ MHz

$f_{synth} = 2724.4000$ MHz

$f_{if} = 545$ MHz

N = 15 M=12

$\rightarrow f_{rf} = 130.8862$ GHz

$\rightarrow f_{laser} = 1962.748$ GHz